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A Method for Evaluating Materiel Readiness of Surface-to-Air Missile Systems

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COMBAT ANALYSIS DIVISION
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A Method for Evaluating Materiel Readiness of Surface-to-Air Missile Systems

by

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FOREWORD

This work is one of a number of publications resulting from efforts undertaken by Project 71.5.1, "Resource Allocation To Meet Operational (Materiel) Readiness Requirements of Surface-to-Air Missile Systems." The primary purpose of this study is to evaluate the support system of the Nike-Hercules and Hawk systems with a view to optimizing the allocation of support resources (piece parts and chassis, test equipment, personnel, and skills). The main publication of the study will deal with this specific allocation problem.

Early in the course of the study it was felt that extant measures of effectiveness were not adequate for study requirements, and as a consequence the study was redefined to state as its first purpose "to develop meaningful, simple, and consistent standards and measuring techniques for materiel readiness of surface-to-air missile systems." This aspect of the study forms the basis of the present paper.

On 28 January 1963, Thomas D. Morris, Assistant Secretary of Defense for Installations and Logistics, in defining areas of emphasis in logistical research, stated that one of the particular areas to be dealt with was the need to "develop and implement systems for measuring the physical readiness of military end items for operational service." Interest at this level happened to dovetail with ongoing work in RAC Project 71.5.1 on the subject of standards of materiel readiness for surface-to-air missile systems. Further, in developing an approach to measuring the physical readiness of these systems, an analog device was constructed and field-tested. The device was demonstrated at the Deputy Chief of Staff for Logistics Policy Council and is currently being considered for use with the Hawk system throughout the world.

The study, originally undertaken within the RAC Weapons Systems Division, is being released by the Combat Analysis Division, its successor under a recent RAC reorganization.

Philip H. Lowry
Chief, Combat Analysis Division

ACKNOWLEDGMENTS

The contents of this document resulted largely from ideas contributed by maintenance and operating personnel at the battery and battalion levels and by command and support personnel throughout the system, including Army Air Defense Command. Accordingly, much of the value in this report must be ascribed to the cooperation and willing assistance of those directly associated with the Hawk and Hercules systems.

CONTENTS

Problem

To develop a meaningful, realistic, and easily implementable method consistent on a worldwide basis for measuring materiel readiness of the Hawk and Nike-Hercules surface-to-air missile (SAM) systems.

Facts

This study was undertaken to meet a Deputy Chief of Staff for Logistics requirement for a measure of materiel readiness in the absence of a satisfactory method. At present, various theaters use various methods* for providing information of this type in addition to the "deadline" report called for by AR 750-45.† The lack of consistency in the field and the difficulty of applying the deadline report to complex electronic systems led to the basic requirement for this study.

Discussion

The materiel-readiness aspect of Project 71.5.1, "Resource Allocation To Meet Operational (Materiel) Readiness Requirements of Surface-to-Air Missile Systems," gave rise to a requirement for a meaningful yardstick to measure the effects of changes in the allocation of support resources (piece parts, chassis, personnel skills, test equipment). Extant methods for evaluating materiel status of SAM systems fail to take into consideration the varying degrees of operating effectiveness of redundant, complex electronic systems. Usual methods for evaluating military equipment are based on a "go–no-go" assumption that does not apply to these systems, which exist in various states of materiel readiness. Evaluation of them according to the best-informed opinions of the most qualified persons varies in terms of experience and emphasis.

No correlation was found between the logistical load placed on the support system and the materiel readiness of the operating equipment. Accordingly

*For example, the "Pearl" report in Korea, the "Red, White, and Blue" report in CONUS, and various but different methods for other theaters.

†Dept of Army, "Materiel Readiness of Selected Equipment," AR 750-45, 9 Mar 62.

two separate indexes were derived: (a) a logistical-load status (LLS) program defining a statistical estimate of the load placed on the support system by a given battery at a given moment in time and (b) a materiel-readiness status (MRS) defining the relative ability of the system hardware to perform its designed function. The LLS index is a normalized percentage based on empirical data and reflecting the status of system components as compared with the logistics load that would result if every piece of equipment in a battery had failed. A value of 0 would indicate that absolutely no load was being placed by a particular battery on the support system at a given moment; a value of 100 percent would define the load when no major end item of equipment in the system was operational.

The MRS defines the materiel capability of a battery to fulfill its designed function as related to the ideal capability (100 percent).

In deriving these indexes it was found that simple, realistic, and implementable methods could be established for the LLS of both Hawk and Hercules and for the MRS of the Hercules system. However, the complexity and redundancy in the Hawk battery necessitated the design of an alternative method of implementation. As a result, a simple electronic analog of the Hawk system was designed as a means of evaluating its MRS.

The results of this study are methodological in nature. They describe an implementable and adaptable approach that can, if necessary, reflect changes in materiel or the tactical deployment of the system; the method was tested with satisfactory results in the field and used in a simulation of the system operations-support complex. The method should provide the tactical commander with reliable information concerning this materiel readiness and the materiel manager with timely and meaningful information concerning the logistical load being placed on the support system. However, this approach is in no sense intended to replace the experienced judgment of the tactical commander or the logistical manager's detailed information concerning system support requirements.

Conclusions

1. The described method provides a realistic, objective, and consistent approach to quantifying MRS and LLS in order to assist both the tactical commander and the logistical manager by providing timely useful information concerning system behavior.

2. The described method is implementable at the field level—directly, for the logistical load for both systems and materiel readiness for the Nike-Hercules system, and with the assistance of an electronic analog in the case of Hawk materiel readiness.

Recommendations

1. The described method for evaluating both MRS and LLS should be implemented as a reporting system from battalion level up, with battalion obtaining battery information directly from the batteries.
2. The Hawk materiel-readiness evaluator (MARE) should be acquired and implemented at battalion level to assist in evaluation of Hawk MRS.

A Method for Evaluating Materiel Readiness of Surface-to-Air Missile Systems

ABBREVIATIONS

AFCC	assault fire-control console
BCC	battery control center
CCJB	crew chief's junction box
ckt	circuit
CONUS	continental United States
c-w	continuous-wave
CWAR	continuous-wave acquisition radar
DA	Department of the Army
DS	director station
E	voltage
FS	firing section
Gen	generator(s)
IFC	integrated fire control
IFF	identification, friend or foe
Ill	continuous-wave illuminating radar
L	launcher
LCT	launch control trailer
LLS	logistical-load status
M	missile
MARE	materiel-readiness evaluator
MRS	materiel-readiness status
MTR	missile-tracking radar
PAR	pulse acquisition radar
R	resistor
ROR	range-only radar
SAM	surface-to-air missile
TS	tracking station
TTR	target-tracking radar

INTRODUCTION

PURPOSE

The development of a method of measuring the materiel readiness of SAM systems constitutes the primary aim of the described effort. (An ancillary aim has been the development of an electronic aid to such evaluation based on a simulation of one of the subject systems—i.e., the Hawk system.) These efforts are dedicated to providing the tactical commander with consistent and reliable information concerning his materiel readiness and to providing the materiel manager with timely and meaningful information concerning the logistical load being placed on the support system.

BACKGROUND

Materiel readiness is here used to define the capability of equipment to perform its designed function as opposed to operational readiness in that the latter includes not only materiel readiness but also personnel readiness and other factors that govern the capability of the battery to perform its designed function as a complex firing unit.

There is no consistent worldwide measure of materiel readiness for SAM systems. Each theater has instituted reporting systems responsive to theater information requirements; interpretations of present Army regulations vary. As a result, a value representing materiel readiness in one theater may not be comparable with that from another theater. The differences may represent interpretative differences in reporting procedures rather than equipment status.

Present methods do not provide a realistic picture of the materiel status of the SAM systems. The present Army regulation, "Materiel Readiness of Selected Equipment," AR 750-45, 9 Mar 62, states:

> Note 1. For the purpose of this section "downtime" or "deadline" is defined as the elapsed time in excess of 10 minutes' duration, during which a firing unit is unable to launch and guide at least one missile to a target, regardless of the conditions of readiness.

The implications are that a missile battery may be considered operational from a materiel standpoint if it is able to fire a missile. In the case of Hawk, a battery could have 0 acquisition capability, less than 50 percent of its control capability, 50 percent of its tracking capability, 17 percent of its launching capability, and 3 percent of its missile capability, and still be considered operational. There is in fact no way for the tactical commander or the logistical manager to know whether a battery that is not deadlined is marginally operational or fully operational from a materiel standpoint.

Another factor involved in providing a realistic picture of the materiel readiness of the subject equipment emerged from discussions with battalion commanders in the field and their evaluations of various configurations of equipment readiness. Because individual battalion commanders place different emphasis on the relative importance of the various major components of the system, radically different judgments of the materiel readiness of various battery configurations result. A unit that one battalion commander would evaluate at a relatively high level of materiel readiness would be looked on by another battalion commander as quite the opposite. This disparity in no sense reflects on the capabilities of the battalion commanders but rather points up that differences in experience factors and emphasis on the significance of the operational status of major components within the system yield inconsistent information.

Although present methods of evaluating equipment readiness show the deficiencies noted, both the tactical commander and the materiel manager have an increasing need for more timely and accurate information. The two systems are deployed today in an operational status that is not at all dissimilar to, if not identical with, the operational demands that would arise in wartime. The SAM units are basically in a wartime posture, imposing a critical requirement for constant and up-to-date information concerning their status at the upper echelons. Further, as a reflection of the effects of technology on attack times, the weeks or days or hours available in the past to prepare for an anticipated attack have been reduced to minutes. As a consequence the demand for a reporting system to provide the commander with timely and realistic information concerning the status of his air defense system is critical.

DESCRIPTION OF THE SYSTEMS

Hawk

The Hawk (Homing-All-the-Way Killer) SAM system uses continuous wave (c-w) radar to guide a supersonic solid-propellant missile to an airborne target.

The equipment in a Hawk battery (see Fig. 1) may be categorized by function as follows: Acquisition is performed by the pulse acquisition radar (PAR) at high altitudes and long ranges and by the c-w acquisition radar (CWAR) at very low altitudes and medium to short ranges. Control is exercised by the battery control center (BCC) or in special cases by the assault fire control console (AFCC). Tracking of the target is performed by either of two c-w illuminating radars (Ill). Launching is accomplished by any one of six trainable launchers, each of which carries three missiles; further, the 18 missiles are usually backed up by 18 more as a reload capability. Power is supplied by three 45-kw generators. Two additional 45-kw generators are provided for missile test and standby.

The components described above are critical and basic to the achievement of materiel readiness. Besides these, the subcomponents of the system include a crew chief's junction box (CCJB), cables (both data and power), loaders to exploit the relocate capability, pallets to hold extra missiles, ancillary vehicles, small arms, and the housekeeping equipment associated with any autonomous unit. Other equipment that increases the effectiveness of the battery under certain circumstances, e.g., the range-only radar (ROR) and the identification, friend or foe (IFF) capability, are not given direct consideration in this paper, since the materiel readiness of the unit does not depend significantly on their status.

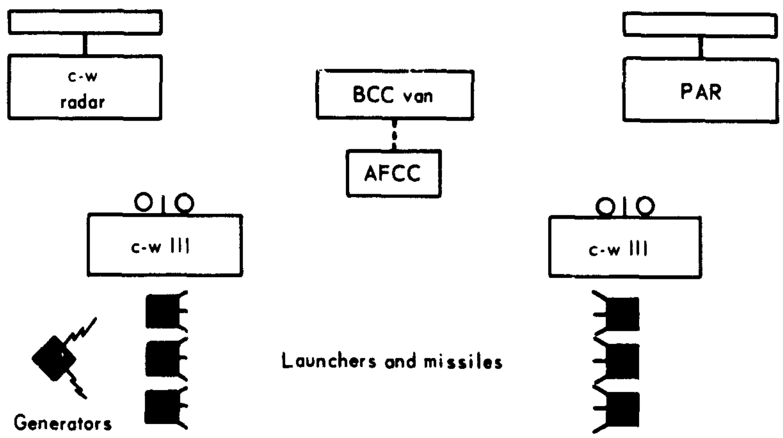


Fig. 1—Hawk Battery Configuration

Interception of the airborne target takes place through the following sequence of events: The target is acquired (by the PAR, the CWAR, or both) and is assigned by the BCC (or possibly the AFCC)* to one of the two independent firing sections (FS). Each FS consists of one Ill connected by a CCJB to three launchers and nine missiles. The BCC uses the acquisition data from the PAR and/or the CWAR to slew the Ill to the approximate position of the target. The Ill then locks on the target and tracks it. The selected launcher is also slewed to the target position, and at a command from the BCC a missile is launched. The missile homes on the signal reflected from the target by the Ill, and its warhead is detonated at the closest approach to the target. After the intercept has been evaluated by the tactical control officer in the BCC, the FS is free to engage new targets.

Nike-Hercules

The Nike-Hercules SAM system utilizes the command-guidance principle to intercept high-performance airborne targets. A Hercules battery is physically separated into two sections: one contains the radars with associated

*The AFCC can handle only one firing section at a time and cannot exploit the PAR.

ground guidance and control equipment and the other, the launchers and missiles (see Fig. 2).

The system can be categorized by function as follows: Acquisition is performed by a PAR located in the integrated fire control (IFC) section of the battery. Tracking of the incoming target and the defensive missile is performed by the target-tracking radar (TTR) and the missile-tracking radar (MTR), both of which are located in the IFC area. Control is exercised by the director station (DS) containing the computer and the battery control console

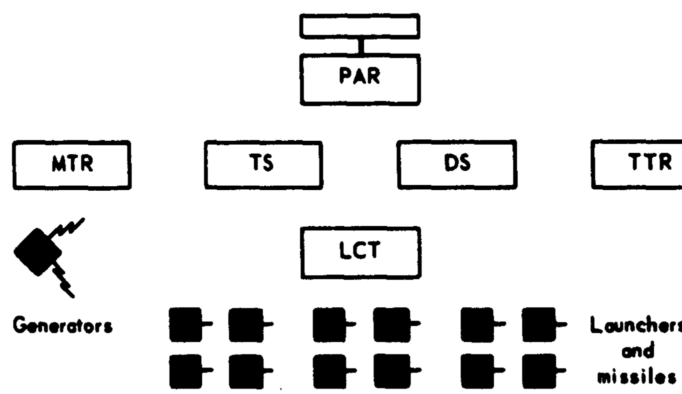


Fig. 2—Hercules Battery Configuration

and by the tracking station (TS) containing the MTR and TTR control consoles. Control in the launching section of the battery is exercised by the trailer-mounted launch control station (LCT), although each of the firing sections (up to four) in a battery can be controlled locally if necessary. Launching takes place in one of the semi-independent firing sections; each contains up to four monorail launchers and the associated monitoring equipment.

Interception takes place as follows: The target is acquired by the PAR, with the acquisition information displayed in the DS. If the battery control officer decides to engage the target, the TTR is slewed to the target and proceeds to track it, transmitting position information to the computer in the DS. A particular firing section is designated and a missile is erected on a launcher. The MTR locks on a beacon in the erected missile by which it will track the missile after launch. At the appropriate time, the launch command is given by the battery control officer, and the missile is boosted from the launcher. The computer receives position information from both the MTR and the TTR and transmits to the missile steering commands that will guide it to a successful intercept. At the moment of nearest approach, a burst command is transmitted to the missile by the MTR, and the missile warhead is detonated.

Fire Distribution

Not included in the above descriptions are integrated fire-distribution concepts (appropriate to both Hawk and Nike-Hercules systems) designed to provide both separate and coordinated acquisition capability and to designate targets to the pertinent batteries, thereby reducing the probability of double kill and more effectively utilizing the air defense resource against a multi-plane attack. These integrated fire-distribution systems, not in themselves part of the batteries, provide basically an ancillary acquisition and designation capability. Their absence would deteriorate effectiveness of the total defense but would not affect the materiel readiness of any given battery. This aspect of the Hawk and Nike-Hercules systems is not considered for purposes of this work, but it is recognized as contributing importantly to overall operational effectiveness.

A METHOD FOR READINESS EVALUATION

CURRENT METHODS

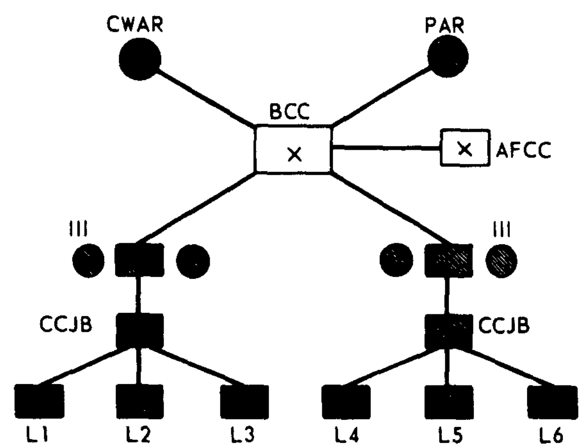
Present methods for reporting materiel status of the two missile systems generally follow from reporting systems based on the deadline concept. This concept has been developed from experience in dealing with those types of equipment whose status may be assumed to be in one of two different states—operational or nonoperational. The missile systems under consideration, however, exist in various degrees of materiel readiness; the go–no-go concept is not easily applicable. The attempt to apply the go–no-go principle to these systems has led to a reporting procedure that is not sensitive to the requirements of realism, consistency, and timeliness.

The tendency of the operations elements of the military to use materiel measurements as reflecting, in a general way, the actual operating characteristics of the equipment suggests that a somewhat more realistic and consistent measure of materiel status would provide significant assistance in both operations- and logistics-oriented military areas. Accordingly the subject missile systems are examined critically to isolate those variables that affect the materiel readiness of the equipment and further, when the effect is partial, to appraise the degree to which the equipment is degraded in terms of its operational effectiveness.

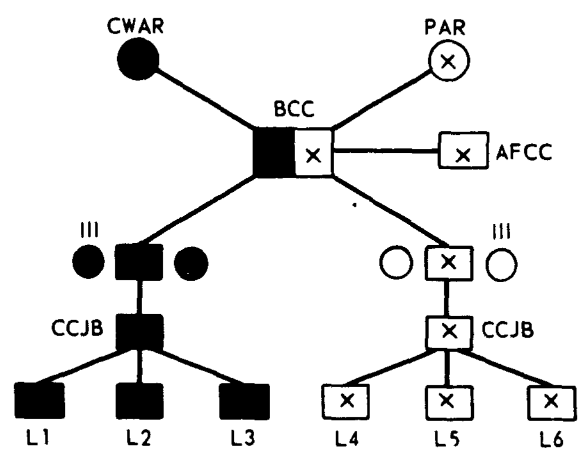
REQUIREMENTS

The method employed for any evaluation of a system applicable to field use must be both realistic and easily implementable. These requirements, in the case of SAM systems, constitute something of a problem when dealing with these systems (particularly Hawk) because allowance must be made for a high degree of complexity and redundancy of function, thus rendering any realistic approach difficult to implement; yet the simplified, easily implementable approaches do not generally provide reliable, usable, or realistic information on materiel status.

In any approach to an evaluation of materiel readiness, the purposes of the evaluation should be borne in mind. A main purpose would be to allocate support resources to maximize missile on-the-air time. An initial assumption was made that the materiel status of the subject equipment would vary inversely with the logistical load, i.e., the support effort required to render the system fully operational, being placed on the support system. After empirical data were tested by means of (a) hypothetical battery configurations and (b) computer simulation of the pertinent systems, using empirical data for inputs, the assumption was shown to be invalid. No correlation could be shown to exist between materiel readiness of either the Hawk or Nike-Hercules systems and the load being placed on the support system; the logistical load as measured by the list



a. Battery completely out of action (tactical situation); two units, possibly only two chassis, to be repaired (logistical situation)



b. Battery 35 percent operational;(tactical situation); at least 16 units to be replaced (logistical situation)

Fig. 3—Relation between Tactical and Logistical Status
Three launchers down means nine missions down.

down operational

of parts-chassis-maintenance-skill requirements was often high in batteries with relatively high materiel status and often low in batteries with low materiel status. A battery may be completely nonoperational and require only a minimal support effort to become 100 percent operational (Fig.3a); conversely a battery may show a significant level of materiel readiness and at the same time place an exceedingly heavy load on the support system (Fig. 3b).

In discussing the development of a method for measuring materiel readiness and LLS the interests of clarity are best served by identifying and developing four different expressions: two for LLS as applied to Hercules and Hawk and two for MRS as applied to both systems.

MEASUREMENT OF LLS

LLS is defined as a measure of the requirements placed on a particular support system at any given time. A measure of requirements in terms of maintenance man-hours and of parts or complex components constitutes a reflection of the logistical load because these are its primary elements. Further, these two elements can be related in terms of dollar values. In considering this measure, an index or some form of quantification is required to provide a basis for comparing different or changing requirements. The logistical-load index is set within the limits from 0—the load placed on the system when every item is "up," requiring no maintenance or support—to 100 percent—every major end item in the battery placing its empirically defined average demand on the support system. A system of proportional "weights"* for different types of components can be obtained by exploiting empirical data on the actual support requirements of the various end items in the missile systems, making feasible a simple and straightforward evaluation of the LLS. In the following formulas the weights are grouped for those pieces of equipment whose requirements, on the occasion of a failure, are similar.

Hercules

For the Nike-Hercules system, considering only those components essential to the immediate readiness of the equipment, the formula may be expressed as follows:

$$\begin{aligned} \mathrm{LLS} = {} & (K_A/3)\,[(\mathrm{PAR}) + (\mathrm{MTR}) + (\mathrm{TTR})] + (K_C/3)\,[(\mathrm{LCT}) + (\mathrm{TS}) + (\mathrm{DS})] \\ & + (K_L/n)\,(L_1 + L_2 + \ldots + L_n) + (K_M/m)\,(M_1 + M_2 + \ldots M_m) \end{aligned} \tag{1}$$

where K_A, K_C, K_L, and K_M are the empirically determined weighting factors for acquisition, control, launch, and missiles, respectively, and n is the number of launchers and m the number of missiles in the battery. The same constant is employed for all three radars because the average support effort required to render each operational after failure is comparable. Similarly the same constant is employed for the TS and DS. Values of 1 or 0, depending on their availability or nonavailability, are assigned to PAR, MTR, etc.

*For missiles in the Hawk system, take a sample of DA 2407 records dealing with the repair of such missiles. When the cost equivalent of the labor hours and parts requirements has been computed, take the mean of this value. Do the same for all other end items of equipment in the battery, weight by numbers of item, normalize to 100, and assign weights appropriately.

Hawk

For the Hawk system, again considering only those components essential to the immediate readiness of the equipment, the formula may be expressed as follows:

$$\text{LLS} = (K_A/2)\,[(\text{CWAR}) + (\text{PAR})] + (K_C/2)\,[(\text{BCC}) + (\text{AFCC})] + (K_I/2)\,[(\text{ILL A}) + (\text{ILL B})] + (K_L/6)\,(L_1 + L_2 + \ldots + L_6) + (K_M/36)\,(M_1 + M_2 + \ldots + M_{36}) \qquad (2)$$

where K_A, K_C, K_I, and K_M are the empirically determined weighting factors for acquisition, control, illumination, launch, and missiles, respectively. Where one constant is used for more than one component, it reflects comparability as noted under Eq 1.

The expression for the LLS, as developed above, provides information for the logistical manager about the load being placed on the support system at a given time. Inasmuch as it is statistically derived (e.g., the average repair times and parts requirements are used as inputs for the constants employed in the equation), immediate application of the values must be considered only in a statistically significant sample size. At the battalion level the values derived from four batteries apply at an acceptable level of confidence.

MEASUREMENT OF MRS

MRS is defined as the materiel effectiveness at a given moment of the equipment under consideration, not as a measure of operational readiness; essential components of the missile batteries are included in the MRS insofar as the degradation of the materiel effectiveness of the battery is a function of the failure of the various end items within the unit. In accordance with this definition, those items not immediately required for effective readiness of the unit are not included in the evaluation. Trucks, for example, although necessary to the continuing operation and support of a battery, do not at any given moment contribute to the materiel effectiveness as defined. Also excluded are the IFF and, for the Hawk battery, the ROR; their contribution to battery materiel effectiveness cannot be appraised without a thorough understanding of the threat.

For purposes of deriving an expression for MRS, the threat is postulated as a random arrival of aircraft, within the postulated acceptable capabilities of the acquisition equipment, at random points in space—i.e., the chances that a plane may approach at 2000 ft and at 20,000 or 40,000 ft are assumed to be equal. A ceiling of 55,000 ft was used in the derivation of values for the acquisition capability. This assumption is based on present modes of deployment of the system. If alternate modes are considered, the expression should be altered appropriately.

From the materiel-readiness standpoint, the function of a SAM battery may be broken down into the following four capabilities: acquisition, control, tracking, and firing. In examining the systems, the variables are divided into two categories—those that result in the complete loss of effectiveness of the unit (lethal) and those that result in a downgrading of the unit effectiveness (debilitating). The loss of any one of the four capabilities noted must necessarily result in a near-total or total loss of effectiveness. Consideration is given to the acquisition capability of the tracking equipment, but this is assumed to be exceedingly limited. If either surface-to-air system under consideration loses all control capability, the value of the system is assumed to go to zero. On the other hand, the loss of a given missile weakens but does not destroy the overall effectiveness of the system.

Hercules

For the Nike-Hercules system the components, in terms of capability, are acquisition, acquisition radar; control,* DS and TS; tracking, TTR and MTR; and firing, launchers.† Although the satelliting of Nike-Hercules units on one or another acquisition net allows the system to maintain a high level of effectiveness even when a given unit has lost its own acquisition capability, nonetheless evaluation of the unit capability should assume its independent operation; accordingly the acquisition potential of the unit is handled as though no such general acquisition net existed.

The following expression, then, is derived—on a brute-force basis—for the MRS of a Nike-Hercules unit. In this approach, component values are usually defined in a go–no-go form that, for these components, is for the most part valid and appropriate. There are times when a radar, for example, may have limited range or be operating with a fringe tolerance; on these occasions the equipment is still held to be operational, since the effect of these operational limits does not substantially affect the materiel status of the whole system. Further, the tolerances described for these systems have a significant built-in safety factor; in many cases the equipment could be actually outside the defined tolerances and still operate effectively.

Acquisition and Tracking. PAR, TTR, and MTR are bivalued—0, nonoperational; 1.0, operational.

$$V_A = (PAR)(TTR)(MTR)$$

V_A is derived value for acquisition and tracking capability.

Control. DS and TS are bivalued—0, nonoperational; 1.0, operational. LCT is not absolutely necessary.

$$V_C = (DS)(TS)$$

V_C is derived value for control capability.

Firing. Each FS is bivalued—1/f, operational; 0, nonoperational, where f is the number of firing sections in the battery.

Each launcher L is bivalued—1/d, operational; 0, nonoperational, where d is the number of launchers in a firing section.

*The launch control station is not included as integral to control since the materiel readiness of the battery is not appreciably deteriorated when this component is eliminated from the system.

†The number of launchers (and missiles) in a Nike-Hercules battery varies considerably from place to place and should be consonant with the actual configuration of the batteries.

Each missile M is bivalued—1/m, operational; 0, nonoperational, where m is the number of missiles in a firing section.

$$V_F = \sum_{i=1}^{f} \left[\frac{(FS_i)}{f} \left(\sum_{j=1}^{d} L_{i_j} \right) \left(\sum_{k=1}^{m} M_{i_k} \right) \right]$$

V_F is derived value for launching and firing capability.

Materiel-Readiness Status.

$$MRS = [(PAR)\,(TTR)\,(MTR)]\,[(DS)\,(TS)] \left\{ \sum_{i=1}^{f} \left[\frac{FS_i}{f} \left(\sum_{j=1}^{d} L_{i_j} \right) \left(\sum_{k=1}^{m} M_{i_k} \right) \right] \right\} \qquad (3)$$

This expression lends itself to facile field manipulation, and no difficulties should be encountered in establishing it as a measure of materiel readiness. An example of a simple form of use may be found in Fig. 4.

Hawk

The Hawk system has a quality of built-in redundancy that makes a corresponding expression of MRS extremely complicated and therefore unfeasible for field application. The effect of the failure of one piece of equipment depends on the status of other pieces of equipment in a unit. For example, the loss of the PAR may result in a serious degradation of materiel effectiveness if the BCC is "up" but may not change the materiel status of the system at all if the BCC is "down" (because the AFCC does not utilize the presentation from the PAR). This type of dependence of the value of any piece of equipment on the status of other pieces of equipment is consistent throughout the Hawk system. Accordingly a straightforward evaluation leads to an expression whose implementation is at best difficult.

The Hawk batteries may be categorized in much the same way as the Hercules battery. The following major components should be considered: acquisition, CWAR and PAR; control, BCC and AFCC; tracking, 2 Ill; and firing, 6 launchers and ±36 missiles.

The following derivation of an expression for the MRS of a Hawk unit is designed to take into consideration the various interrelations between the components of the system, which make it necessary for the final expression to be something more than a simple relating of the various component equations.

Acquisition. Based on approximate space-volume coverage for random arrivals and the assumption of a limited ceiling, the area overlap between PAR and CWAR is 0.34. Both PAR and CWAR have capabilities of 0.33; the residual Ill capability is 0.1. Therefore

$$V_A = 2/3\,(CWAR) + 2/3\,(PAR) - 1/3\,(PAR)\,(CWAR) + 1/10\,(CWAR-1)\,(PAR-1)$$

where PAR and CWAR are bivalued—0, nonoperational; 1.0, operational.

Control. BCC is trivalued—0, nonoperational; 0.5, one section deadlined; and 1.0, operational. AFCC is bivalued—0, nonoperational; 1.0, operational.

MATERIEL READINESS STATUS

(NIKE Hercules)

1. Integrated Fire Control (IFC) Section

Fill in blanks below as indicated; if equipment is operational, insert a 1; if non-operational, insert a 0:

A Acquisition Radar
B Target Track Radar
C Missile Track Radar
D Director Station
E Tracking Station

(A) (B) (C) (D) (E) (__) (__) (__) (__) (__) · [ ]

IFC Value

2. Firing Sections

Fill in blanks below as indicated; Status = $\frac{\text{number operational}}{\text{number assigned}}$

Example: $\frac{\text{4 missiles operational}}{\text{6 missiles assigned}}$ .67 Status

	Missile Status		Launcher Status		Fire Section Status
Fire Section 1	[ ]	×	[ ]	=	[ ]
					+
Fire Section 2	[ ]	×	[ ]	=	[ ]
					+
Fire Section 3	[ ]	×	[ ]	=	[ ]
			Total		[ ]
					F.S. Value

3. Battery Materiel Readiness Status (BMRS)

BMRS $= \frac{\text{(IFC Value) (F.S. Value)}}{3} = \frac{[\ ] \times [\ ]}{3}$ [ ]

Materiel Readiness

Fig. 4—Materiel-Readiness Evaluation Form for Nike-Hercules

Therefore

$$V_C = (BCC) + (BCC - 1)(BCC - 0.5)(AFCC)$$

Firing. Each FS consists of 0.5; each Ill, 1.0; each launcher, 0.33; and each missile, 0.11.* Therefore

$$V_{FS} = (0.5)(Ill)\left(\sum_{j=1}^{3}\left\{\frac{1}{3}L_j\left[\sum_{i=1}^{3}\left(\frac{1}{3}M_{ij}\right)\right]\right\}\right)$$

Materiel-Readiness Status. After appropriate modification† to account for various equipmental interactions, the expression becomes

$$\begin{aligned} MRS = \{&(PAR)[(2/3) - (4/3)(BCC-1)(BCC-0.5)] + 2/3\,(CWAR) \\ &- 1/3\,(CWAR)(PAR)[1 - 2(BCC-1)(BCC-0.5)] + 1/10\,(CWAR-1)(PAR-1) \\ &+ 1/5\,(PAR)(CWAR-1)(BCC-1)(.5-BCC)\} \times \Bigg(BCC\,(BCC \\ &- .5)\left\{(Ill)\sum_{j=1}^{3}\left[\left(\frac{1}{3}L_j\right)\sum_{i=1}^{3}\left(\frac{1}{3}M_{ij}\right)\right]\right\} + [BCC\,(1.5 - BCC) \\ &+ (BCC-1)(BCC-0.5)(AFCC)] \times \left\{(Ill)\sum_{j=1}^{3}\left[\left(\frac{1}{3}L_j\right)\sum_{i=1}^{3}\left(\frac{1}{3}M_{ij}\right)\right]\right\}\Bigg) \end{aligned} \tag{4}$$

*In dealing with materiel steadiness at a given moment only, the missiles on launchers are included. In the case of a missile failure, it is assumed that the battery is degraded because of the loss of that missile until an operational missile has been replaced on the launcher.

†This reflects consideration of the interdependence of the different elements in a battery for purposes of evaluating materiel readiness. The derived equation is complicated by the requirement for taking these interactions into consideration. Accordingly the interdependences and redundancies are handled in simple brute-force algebraic form, with subsequent combining of terms. The complexity thus introduced is necessary to represent realistically the actual relations between the system components.

IMPLEMENTATION OF EXPRESSIONS

GENERAL METHODS

In dealing with any form of quantification for practical use, a method of implementation must be found that will enable the user (in this case the commander in the field) to exploit the quantification without excessive effort and opportunity for error. The usual methods for implementing quantitative techniques are (a) closed analytical method (formulas, equations, computations); (b) checklist or form (Yes or No, Go or No-Go, etc.); (c) nomograph (multidimensional graphs); and (d) electronic or mechanical computational aid.

In the case of the LLS, no difficulties should be anticipated in using a closed analytical method or a checklist to provide the desired information. Implementation, then, of the derived expression satisfies the requirement of simplicity set forth in the section "A Method for Readiness Evaluation."

PROBLEMS OF HAWK UNITS

Implementation of the derived expression for materiel readiness, on the other hand, requires somewhat lengthier consideration because of the complexity of the expression, particularly in the case of Hawk. For Nike-Hercules the closed analytical method, using the expression developed previously, seems feasible for use in the field, since the computations are reasonably straightforward.

For Hawk, however, the first method is impractical because of the complexity of the expression and the second is restricted by the possible number of configurations in the system (more than 6000, excluding missile variables). The third method does not lend itself to the nature of the expression because such functions as double summations are not easily accommodated in nomographic form without introducing a high level of complexity. The fourth method is fairly simple to construct and use and involves basically an analog of the missile system in question. Its sole function is to evaluate the system, as appropriate, on the failure of any component within the system, taking interrelations of the various components into consideration by certain switching techniques.

A mock-up of an electronic evaluation device, the Hawk MARE, was constructed and tested in both the laboratory and the field. The values used in designing this piece of apparatus were based on the Hawk materiel-readiness expression (see Eq 4). The LLS expression (Eq 2) was also added to the circuit to provide supplemental information.

A description of the analog device and its circuitry appears in App A. The general values used in the expressions for both the LLS and the MRS of the Hawk unit and replaced in the circuits are in no sense fixed, and the device is submitted as a methodological approach that could be an exceedingly useful aid to both the tactical commander and the materiel manager.

For laboratory purposes, a simple set of tables having approximately 100 entries has been developed for evaluating Hawk MRS. This tabular form reduces the more than 6000 possible configurations to a more workable 100 configurations through the use of simplifying and connecting assumptions. For example, the user must mentally aggregate such entries as "operable missiles on operable launchers, connected to an operable illuminator" before using the tables. The mental computation required in conjunction with the use of the tables allows numerous opportunities for error, even if the user is experienced in the procedure. Another disadvantage is that the tables give a value for materiel readiness only. As will be shown, the LLS is also important to the field commander.

Obviously the tables would be less expensive to produce than an electronic analog device, but the advantages of the electronic device (speed, versatility, low chance of error, provision of both MRS and LLS—all with virtually no training requirement and no mental-computation requirement) seem to outweigh the cost differential. The tabular form might be useful at higher echelons, but for field use the electronic device seems more suitable.

APPLICATION OF EVALUATION METHOD

The described methodology for evaluating materiel readiness is designed to provide realistic, consistent, and useful information to the tactical commander and the materiel manager at all levels of command. Since statistical derived values are used, particularly in the LLS,* the level of resolution of application should probably be at the battalion level.

Using the derived expressions, it is possible for the battalion commander to acquire a feeling not only for his MRS but also for the differing logistical loads placed on his support system by the various batteries under his purview. He can also examine the effect of allocating his support resources to obtain maximal materiel readiness with a given support capability. Particularly at levels above the battalion, the developed expressions provide a realistic and meaningful measure of the materiel status of the SAM systems for the appropriate tactical commander. The method also provides the logistical manager with an evaluation of the effect on the total logistical system of changing logistical loads. At the highest level, the system substitutes consistency and realism for a current reporting system subject to wide variation in interpretation.

Several examples of the manifold possible applications of the evaluative method described follow.

In the case of a battalion commander or supply officer dealing with the allocation of his support resources (at this level, the direct support unit), a typical situation is shown in the accompanying tabulation. The four batteries

Battery	MRS	LLS
A	0	5
B	35	40
C	90	22
D	85	4

are described in terms of both the MRS and estimated LLS of each unit. Consistent with comments in the section "A Method for Readiness Evaluation" concerning the lack of correlation between the LLS and the MRS, the information presented provides the decision maker with clear and realistic data to assist him in his allocation. The above tabulation shows that a relatively small support effort applied to one of the batteries (Btry A) will have a high payoff. Although another battery has a higher MRS, a significant improvement in its materiel effectiveness would place a heavy support load on the system.

*The loading factors used (the "K's") are based on mean values for empirically derived distributions of the consequences of end-item failures.

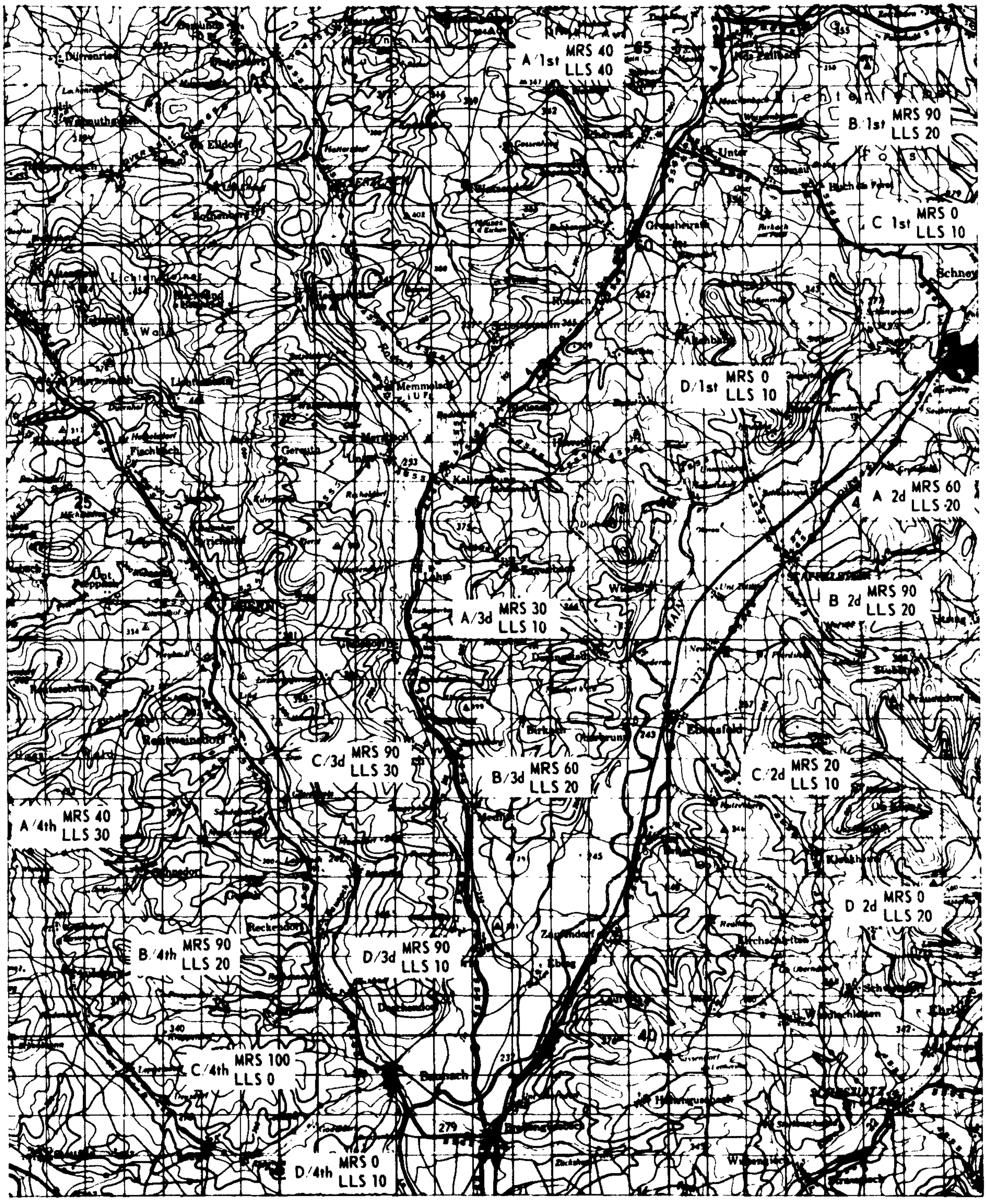


Fig. 5—Evaluations of SAM Group with 16 Batteries Deployed

Another example of the application of the values derived by the method described may be found in Fig. 5, which displays a SAM group with 16 batteries deployed. Associated with each battery are the MRS and the LLS. The group commander called on to sharpen his defense posture can recognize from the data provided in Fig. 5 a number of factors that could help him decide which batteries he could best bring up from 2-hr status. He can see that battery A/1st, although operational, is placing a heavy load on the support system, implying that this battery might not have the resilience or the redundancy to deal with further failure. Accordingly the commander might make the decision to place his emphasis on bringing up batteries C/1st and D/1st from a totally nonoperational status rather than on dealing with battery A/1st at the moment. Further consideration of this illustration shows many ways in which the data provided could be useful in aiding the tactical commander and the logistical manager in their decisions.

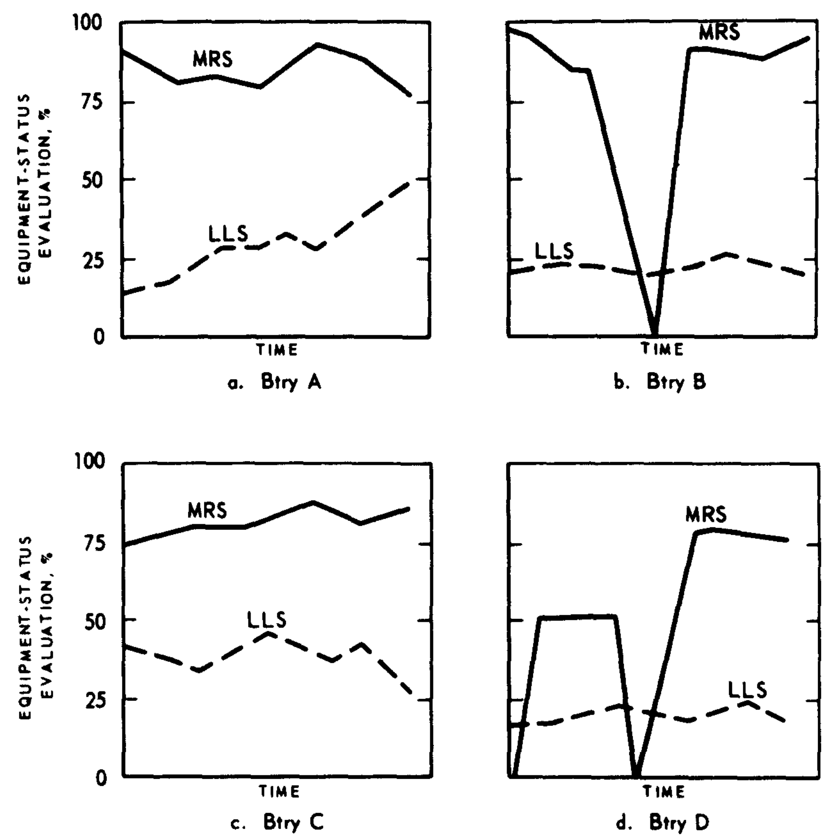


Fig. 6—Logistical-Load Status and Materiel-Readiness Status of Four Batteries

Figure 6 illustrates daily charting of the LLS and MRS of four batteries. In this case the logistical manager is in a position to note a situation developing in one of the batteries (Fig. 6a) before it becomes critical. He can see from this chart that although the MRS of this battery seems to be holding its own, the logistical load it places on the system is steadily increasing. He will know from past experience that the effect of this is that the demand eventually exceeds the support capability and the battery in question requires special attention and assistance. Thus he should be able to anticipate and correct a potential problem before its effects are serious.

Another application includes the special use at the highest echelons of the realistic information concerning the materiel status of the equipment. When the Hawk MARE was tested in the field, it was found to have exceedingly valuable training attributes for the battalion commander in dealings with his battery commanders.

The devised method is designed to provide additional simplified information for both operations and support personnel at various echelons, aiding in the implementation of timely and realistic decisions aimed at maintaining maximal on-the-air time of missile systems. It is not designed, and should not be applied, as a substitute for judgment or decision or in any sense a replacement for detailed information concerning the status of components of the systems.

CONCLUSIONS AND RECOMMENDATIONS

Although this analysis is methodological in nature, the approach defined is felt to have direct implementable significance in the Nike-Hercules and Hawk systems. The precise values to be used in the expressions are obtainable from empirical records concerning systemic demands and are further subject to change in the light of variations in support requirements as functions of geography, climate, experience factors, and other pertinent variables.

The readings provided by these expressions may be used as a numeric form or may be coded by color or in some other fashion and do not reflect a level of precision such that a 1 percent change is significant (based on the input data used for establishing the constants for the expressions).

CONCLUSIONS

1. The described method of quantifying MRS and LLS provides a realistic and consistent approach to the evaluation of the subject equipment status.
2. The described method for evaluating MRS and LLS is implementable in the subject systems.
3. The Hawk MARE provides a basis for implementing the Hawk materiel-readiness evaluation.

RECOMMENDATIONS

1. The described method for evaluating both MRS and LLS should be implemented as a reporting system from battalion level up, with battalion obtaining battery information directly from the batteries.
2. A Hawk MARE should be acquired and implemented at battalion level to assist in evaluation of Hawk status.

Appendix A

HAWK MATERIEL-READINESS EVALUATOR

Figures

The following description is based on values that can be derived from empirical data on the materiel requirements of the Hawk SAM system. These values should be considered subject to modification in the light of changes in the activities described. Further, this description should be considered a basic methodological approach, with input data to be derived from available records.

Circuit description covers MRS, LLS, and a testing capability. A detailed schematic (Fig. A1) and a simplified schematic diagram (Fig. A2) may aid in following the discussion.

The MRS circuit is a series-parallel resistance network that feeds a voltage to a high-impedance metering circuit. The voltage E at this point is varied from E/2 to 0 by switching resistances in and out of the network. (It should be noted that R′ varies inversely with R″ to maintain a total resistance of R at all times. This particularly useful feature is utilized in the testing circuit. The reason for this arrangement is clear if reference is made to the MRS and testing equivalent-circuit diagrams.)

R′ and R″ are in parallel with the resistances 0.63R, 1.21R, and 0.16R. As the resistances R′ and R″ are switched from D, C, and B to A, the voltage E′ will be modified as follows: at D, the value varies from E/2 to 0; at C, the value varies from 0.81E/2 to 0; at B, the value varies from 0.15E/2 to 0; at A, the value is 0 only. The switching of the network R′, R″ to these points is accomplished by the switches BCC, PAR, AFCC, and CWAR.

A more detailed simplified schematic (Fig. A3) is provided to show the function of the various switches in the R′, R″ network. The detailed simplified schematic of the MRS circuitry shows the R′ and R″ network and a series-parallel network of resistors switched in or out by various switches. For simplicity all switches are not shown. At each point M1a to M6c, and L1 to L6 of the R′ network and at M1a to M6c, L1 to L6, Gen A, Ill A, Gen B, and Ill B of the R″ network, a switch contact is actually present but is not shown on this schematic. With all systems go, R″ network has maximum resistance 2R and R′ minimum resistance 0. As components or systems fail, resistances of the R″ network are shorted out and simultaneously equivalent resistances are switched in at the R′ network.

Switches shown are in the "on" or "full-up" position. Across R′ network all resistances are shorted out and at the R″ network all resistances are switched in.

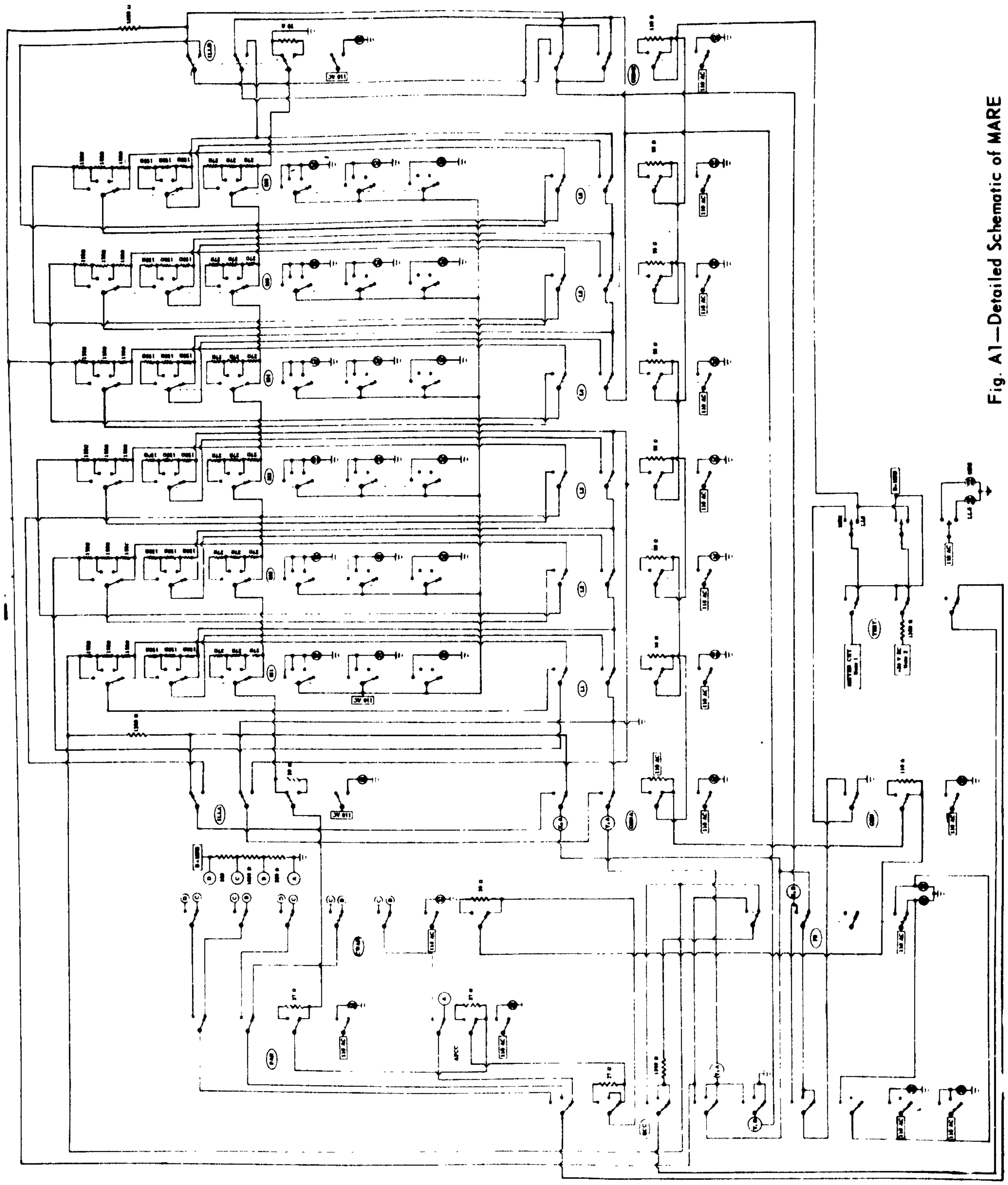
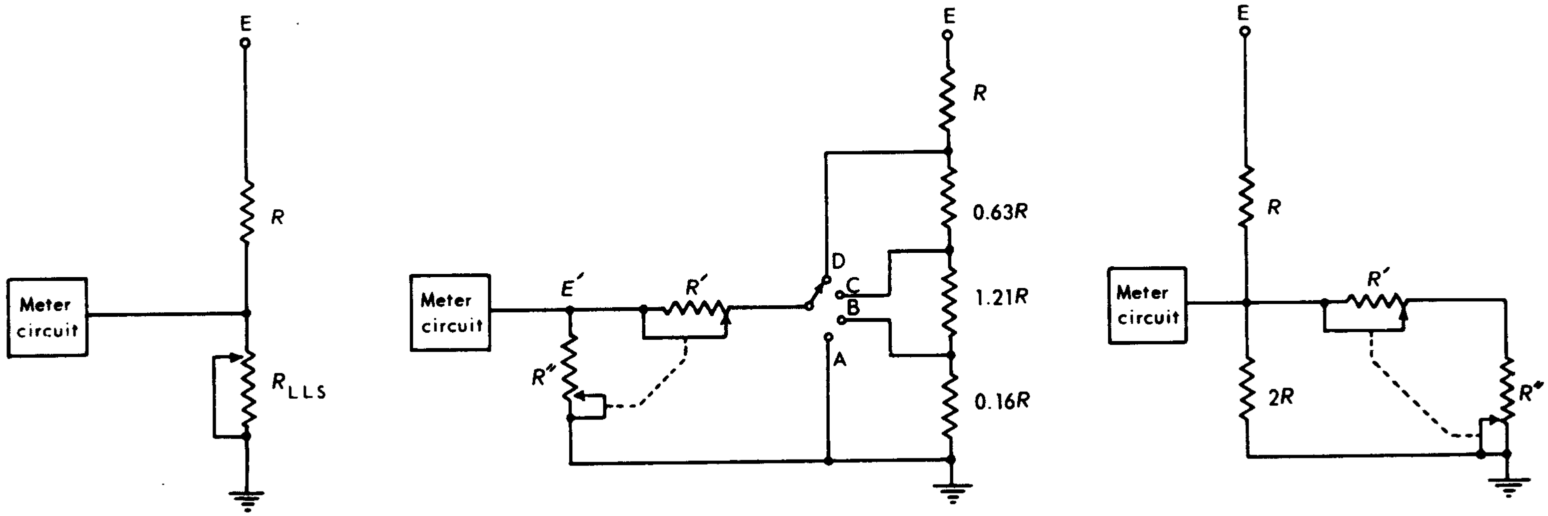


Fig. A1—Detailed Schematic of MARE



a. LLS equivalent circuit

b. MRS equivalent circuit

c. Testing circuit

Fig. A2—Simplified Equivalent-Circuit Diagram of LLS, MRS, and Test Configurations

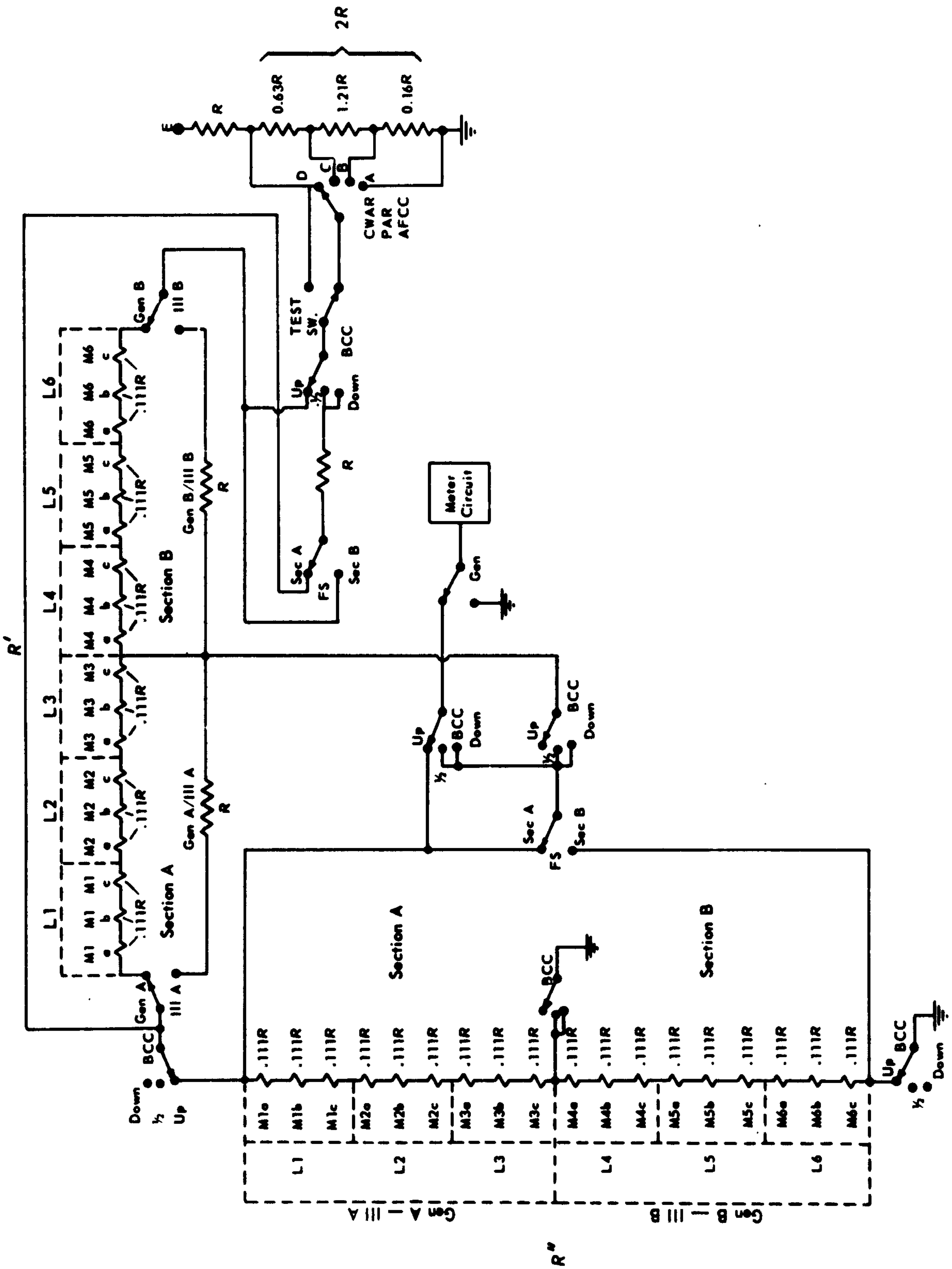


Fig. A3—Detailed Equivalent-MRS Circuitry of MARE

The resistances 0.63R, 1.21R, and 0.16R are in an easily removable plug-in unit. This provides a convenient method for changing these values if at a later time it is determined that they should be modified. The meter circuit is adjusted to read E/2 at full-scale deflection 100. Because of the high-input impedance and the characteristic of the transistor circuit, the indicated meter readings from 0 to 100 will be as accurate as the limitations of the meter itself allow. A 0-1 ma movement was chosen for this circuitry. Provision is also made for an external recording meter, which provides a permanent record with a time base on paper tape.

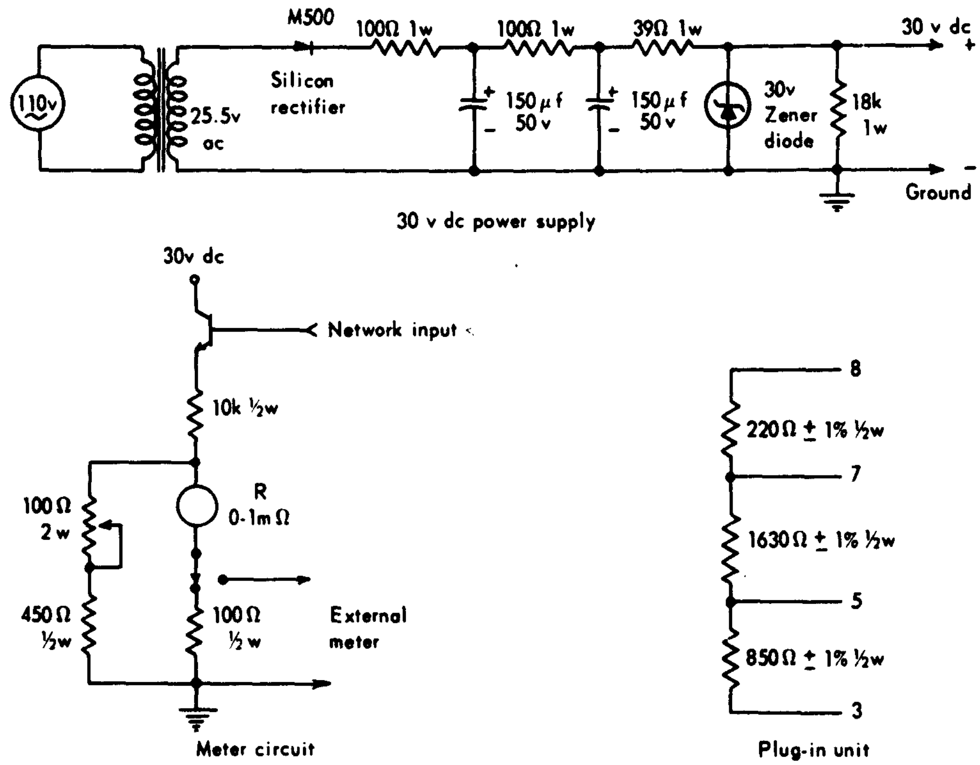


Fig. A4—Power Supply, Meter Circuit, and Plug-In Unit of MARE

To set the meter to 100, a 100-ohm potentiometer in parallel with the meter movement is adjusted for the full-scale reading. This adjustment, however, can be made only after depressing the SET 100 button. The MRS network resistances, represented by R′ and R″, are removed from any of the points C, B, or A and returned to point D by depressing the SET 100 button. Also, the meter circuit is removed from the junction R′, R″ and connected to the junction R, 2R represented on the equivalent-circuit diagram. This allows an accurate setting of the meter circuit regardless of the settings of the MRS and LLS switches by using the actual network resistances.

The resistance in series with the meter movement (100 ohm) is equivalent to the resistance of the external meter movement, thus allowing the switching in and out of the external meter with no effect on the internal meter.

LLS is simply a series of resistances switched in or out by the various switches. This is represented on the LLS equivalent-circuit diagram by R_{LLS}. R_{LLS} is independent of the MRS network and merely indicates, as the elements are switched out, an increase at the meter proportional to the "weight" of the switched-out element. With all elements out, the meter will read 100. As elements are switched in, the meter reading will decrease to 0.

A standard half-wave rectifier is provided (Fig. A4) for the network voltage. A Zener diode regulates the output to a constant voltage as long as

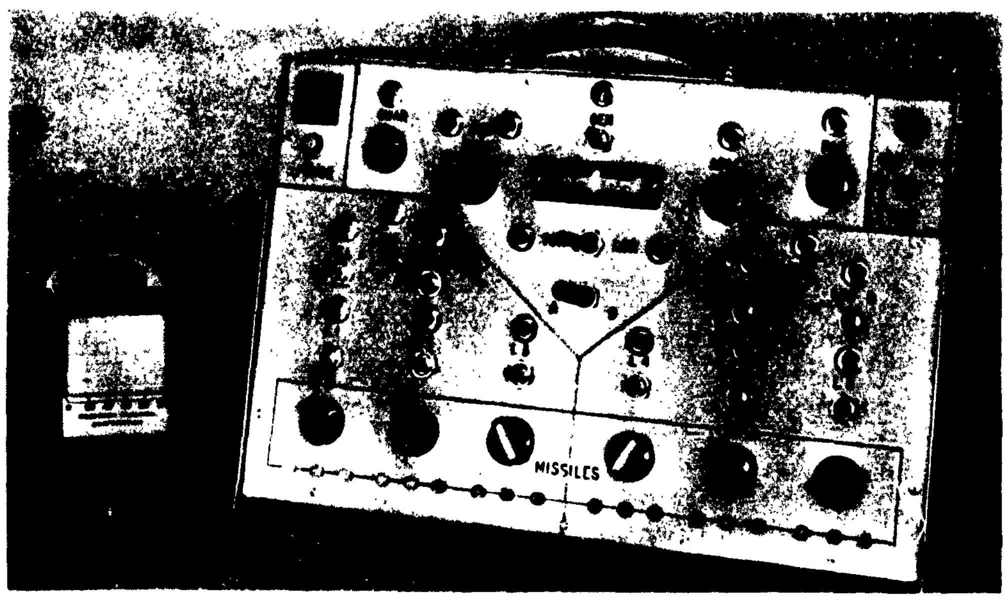


Fig. A5—Mock-up of Hawk MARE

the input voltage remains above the Zener breakdown level and the output current does not exceed the rating of the Zener. The latter is unlikely because of the conservative rating of the Zener. Line-voltage fluctuations of -10 to +20 percent have been effected without noticeable output-voltage change.

Neon lights (NE-1s) are provided on the front panel to indicate which elements are switched out.

Switches on the schematic diagram (Fig. A1 are shown in the full down or off positions. The FS switch is shown in position A.

A mock-up of the Hawk MARE is shown in Fig. A5.